❑ These slides/notes represent only part of the course, and were accompanied by face-to-face explanations on white-board and additional topics / learning materials.

❑ In preparation of these slides I have also benefited from various books and online material.

❑ Some of the slides contain animations which may not be visible in pdf version.

❑ Corrections, comments, feedback may be sent to https://www.linkedin.com/in/naveedrazzaqbutt/

ES 691
Mathematics for Machine Learning

with

Dr. Naveed R. Butt

@

GIKI - FES

Introductions …

- Me
- You
- The Course

GIK Institute

BS in Engineering Sciences

[1998 - 2002]

Automation Engineer [2002 - 2004]

Riyadh Water Transportation System's SCADA upgrade project

KFUPM

MS Student/Staff [2004 - 2006]

- MS in Systems Engineering
- Thesis in NN-based Nonlinear Modelling & Control
- Teaching (labs: DSP, Control)

LTH

[2006-2014]

- **Positions: PhD Student/Staff, Postdoc, Research Associate**
- **PhD in Engineering (focus: Statistical Modelling & SP)**
- **Teaching + Research**

Ericsson Research

[2014 - 2018]

- Senior Researcher
- Research + Patenting
- Next Generation WiFi & 5G

Jouf University [2018-2020]
Assistant Professor
College of Engineering

- **Badminton, Bowling**
- **Weekend dinners**
- **Reading, Writing (poetry, short stories)**

Roles

Teacher

Researcher

As a teache

Full Courses

- **Estimation & Detection Theory**
- **Statistical Signal Processing & Modelling**
- **Stochastic Processes**
- **Signals and Systems**
- **Probability & Statistics**
- **Wave Propagation & Antennas**
- **Principles of Communications**
- **Digital Communications**
- **Satellite Communications**
- **Circuit Analysis II**

Labs & Tutorials

- **Time Series Analysis**
- **Signal Theory**
- **Advanced Control**
- **Modern Control Systems**
- **Digital Design**

Supervision

Supervised and collaborated in various grad and postgrad theses.

As a researcher

Mathematical Modeling & Machine Learning

Spectroscopy
- Nuclear Quadrupole Resonance (NQR) signal detection
- Raman Signal Classification

Spectrum Estimation
- Missing Samples Cases
- Poly-spectra
- Coherence Spectra

Beamforming
- Radar & Sonar
- Pitch Estimation

Communications
- WiFi & 5G
- Antenna Arrays

Control & Others
- NN-based Nonlinear Plant Modelling & Control
- Physics Informed Neural Networks

INTER-DISCIPLINARY MACHINE LEARNING INITIATIVE

iMLi

Inter-Disciplinary Machine Learning Initiative (IMLI)

Faculty of Engineering Sciences

GIK Institute

Ali Haider Shah

MS Engineering Sciences (Applied Mathematics)

Session: 2022 (Fall) - 2024 (Spring)

Research Field: PINNs, GNNs, CNNs

Email: ges2264@giki.edu.pk

About iMLi:

I'm Ali Haider Shah, privileged to be part of the IMLI research group under the kind supervision of Dr. Naveed Razzaq Butt at FES. My focus is on exploring the mathematical and statistical foundations of Machine Learning to advance state-of-the-art research in this field.

Faraz Mukhtiar

MS Engineering Sciences (Applied Mathematics)

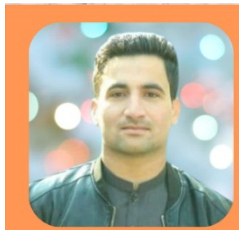
Session: 2023 (spring) - 2025 (Fall)

Research Field: ML based Control Charts

Email: ges2316@giki.edu.pk

About iMLi:

I am pleased to be part of the IMLI research group, where my work focuses on integrating machine learning with statistical quality control tools, especially control charts, to improve their efficiency and effectiveness in quality control.



Dildar Shah

MS Engineering Sciences (Applied Mathematics)

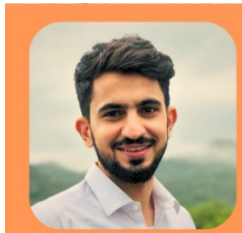
Session: 2023 (Fall) - 2025 (Spring)

Research Field: Neural Network Pruning, Evolutionary Graph Theory

Email: ges2371@giki.edu.pk

About iMLi:

It's an immense pleasure to be part of the IMLI research group at the faculty of engineering sciences. My goal is to build such models that can be easily run on a CPU and mobile devices with the help of Neural Network Pruning.



Usama Mangol

MS Engineering Sciences (Applied Mathematics)

Session: 2023 (Fall) - 2025 (Spring)

Research Field: Adaptive Filtering

Email: ges2372@giki.edu.pk

About iMLi:

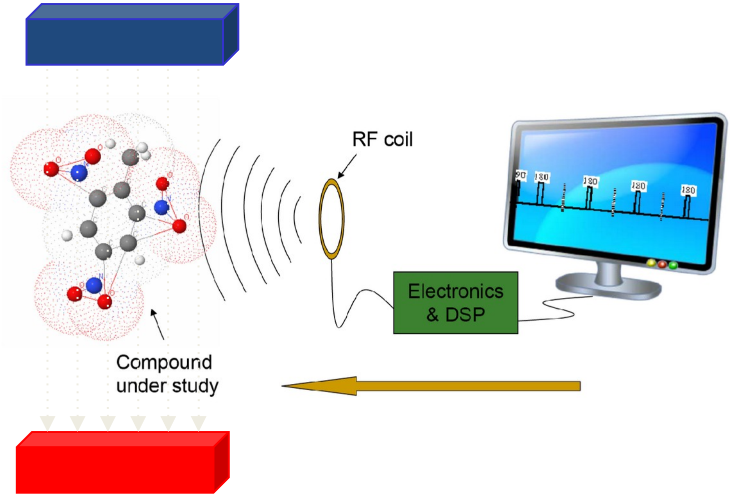
I am delighted to be involved with the iMLi research group, Our research integrates adaptive filtering techniques with machine learning to enhance the accuracy and robustness of predictive models and data-driven solutions.

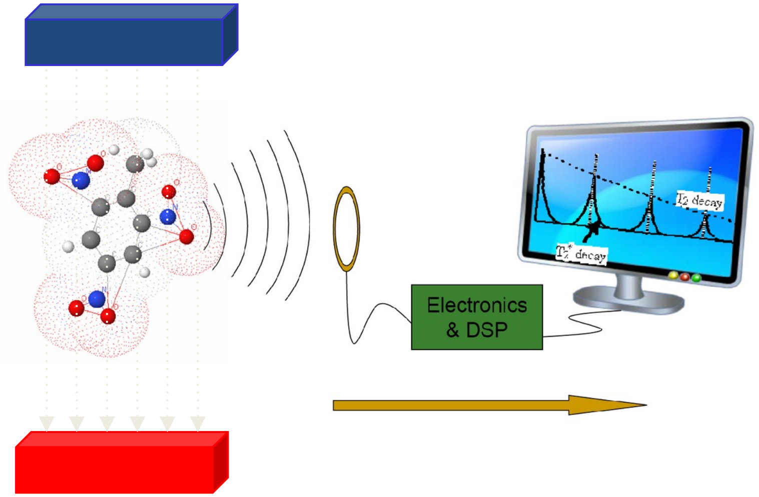
One of my research projects…

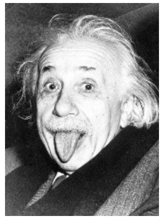
CONPHIRMER Project

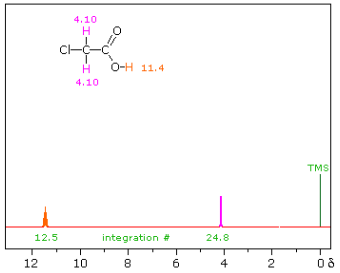
Question: how to quickly tell whether a medicine is fake?

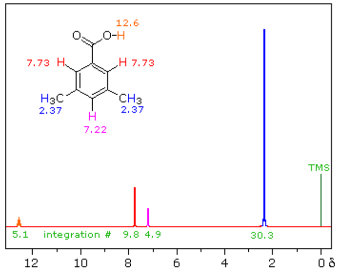
NMR vs. NQR


RF coil
Electronics & DSP
Compound under study
90
180
180
180
180

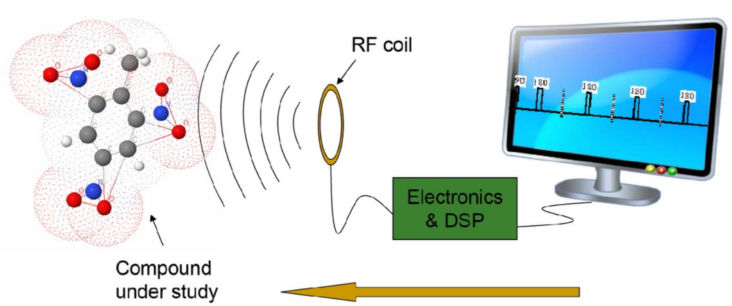

Electronics & DSP
T_2 decay
T_2^* decay

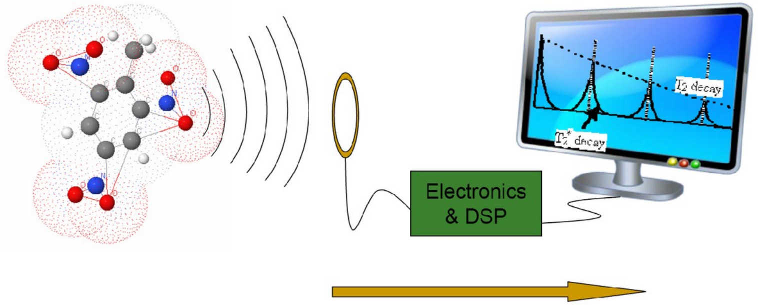


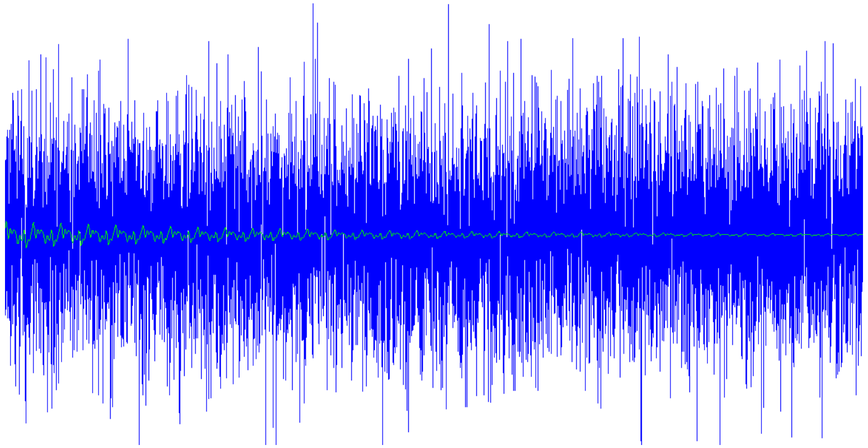

4.10
H
Cl
C
C
O
H
O-H 11.4
4.10
TMS
12.5
integration #
24.8
12
10
8
6
4
2
0 δ


12.6
O
O-H
7.73 H
H 7.73
H_3C
2.37
CH_3
2.37
H
7.22
TMS
5.1
integration #
9.8
4.9
30.3
12
10
8
6
4
2
0 δ

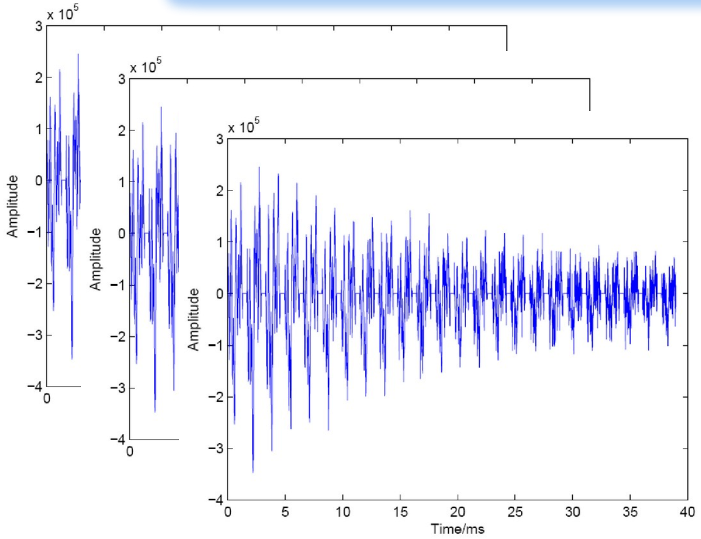
NQR Signal

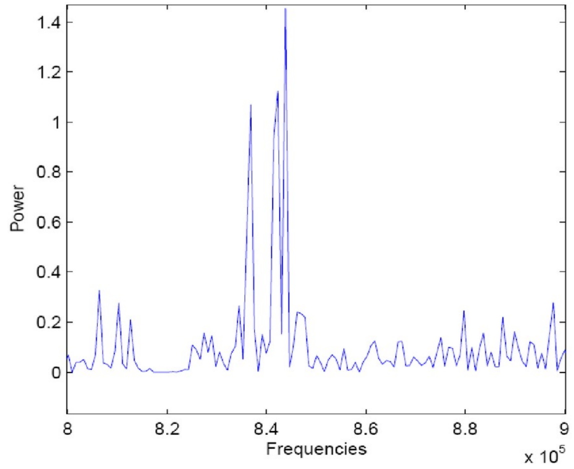

RF coil
90
180
180
180
180
Electronics & DSP
Compound under study


T_2 decay
T_2^* decay
Electronics & DSP



NQR Signal Modeling & Detection





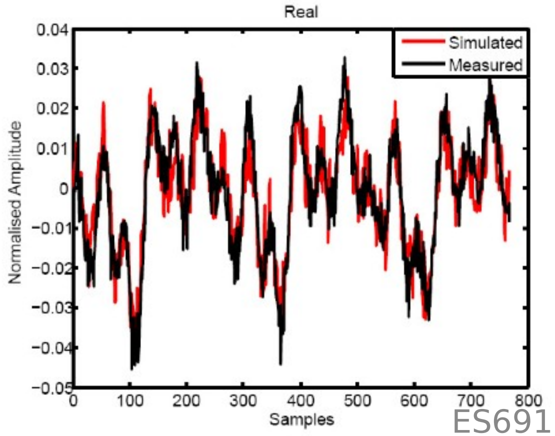
Study Features

$$y_m^{(p)}(t) = \sum_{k=1}^{d^{(p)}} \alpha_k^{(p)} e^{-(t+m\mu)\eta_k^{(p)}} e^{-\beta_k^{(p)}|t-t_{sp}|+i\omega_k^{(p)}(T)t}$$

$$\omega_k^{(p)}(T) = a_k^{(p)} - b_k^{(p)}T$$

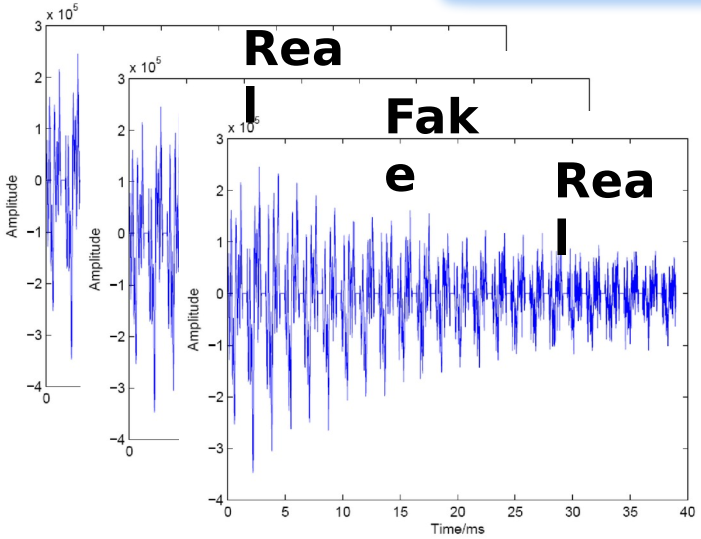
$$\alpha_k^{(p)} = \rho\kappa_k^{(p)} \qquad \left\|\boldsymbol{\kappa}-\boldsymbol{\kappa_a}\right\|_2^2 \le \epsilon$$

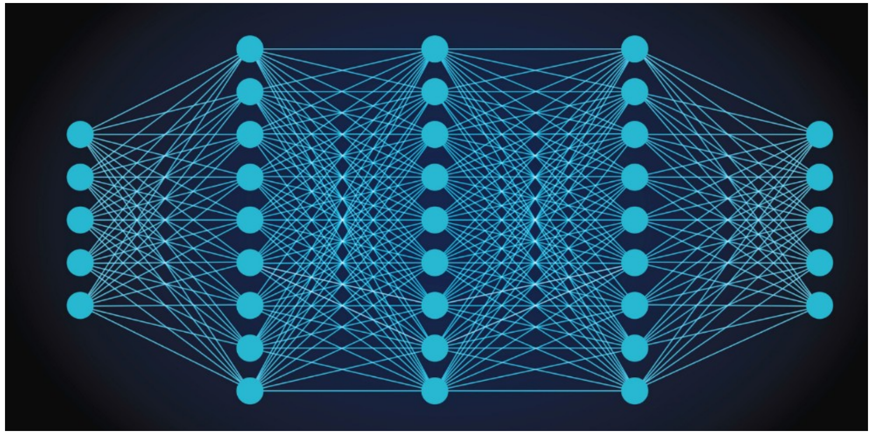
Model the Data Mathematically



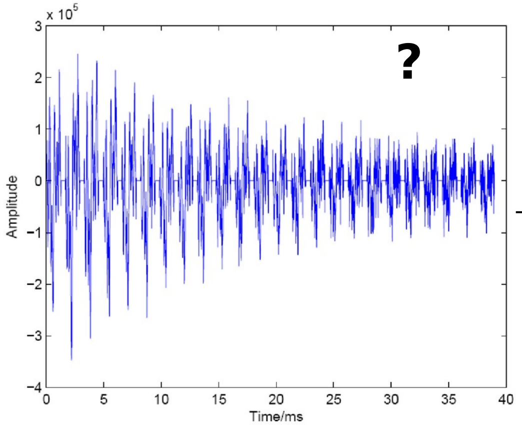
Apply Estimation & Hypothesis Testing

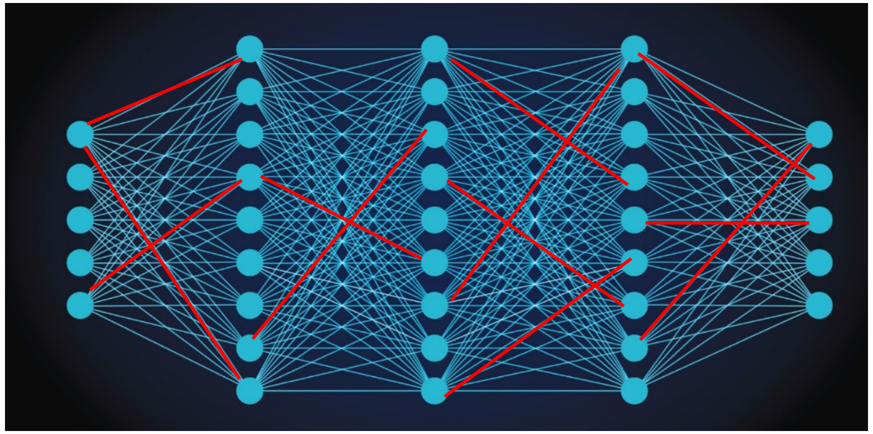
NN-based Identification





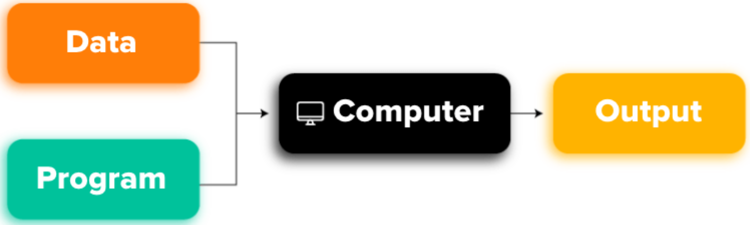
Neural Network Being Trained



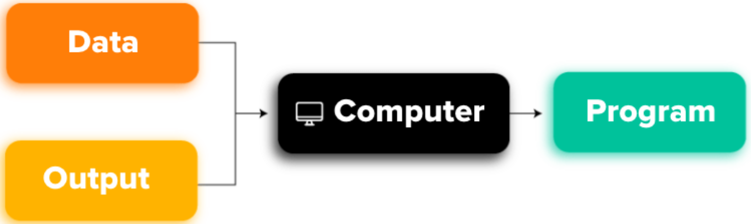


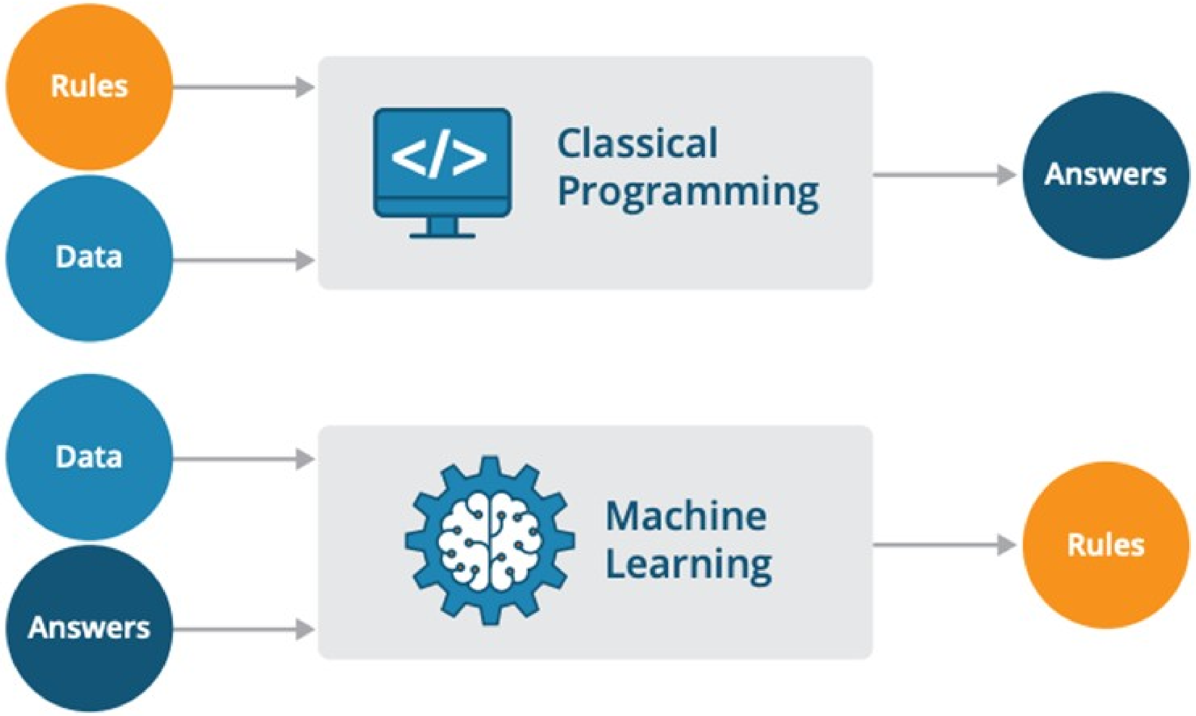
Trained NN Working as Model and Classifier

TRADITIONAL PROGRAMMING



MACHINE LEARNING





Introductions …

- Me
- You ⇦
- The Course

The Course …

- Why study MFML?
- How is the content organized?
- Where can I apply what I learn?
- How is the course conducted and assessed?

The Course …

- Why study MFML? **(REALLY?)**
- How is the content organized?
- Where can I apply what I learn?
- How is the course conducted and assessed?

The Course …

- Why study MFML? **(REAL?)**
- How is the content organized?
- Where can I apply what I learn?
- How is the course conducted and assessed?

The need for skilled professionals who can harness the power of machine-learning while having the right mathematical skills to analyze, interpret, and leverage data keeps growing. Proper mathematical understanding of these tools is also critical for possibility of improving them.

The Course …

- Why study MFML?
- How is the content organized?
- Where can I apply what I learn?
- How is the course conducted and assessed?

This course is divided into three parts: Magic, Mathematics, and “Mathemagic”. In the first part we talk about the “magic” of how learning happens (in organisms and algorithms). In the second part, we cover the mathematical concepts that enable algorithmic learning. And in the third part, we see how the concepts of learning and mathematics come together to produce the “brains” of AI, called Machine Learning.

The Course …

- Why study MFML?
- How is the content organized?
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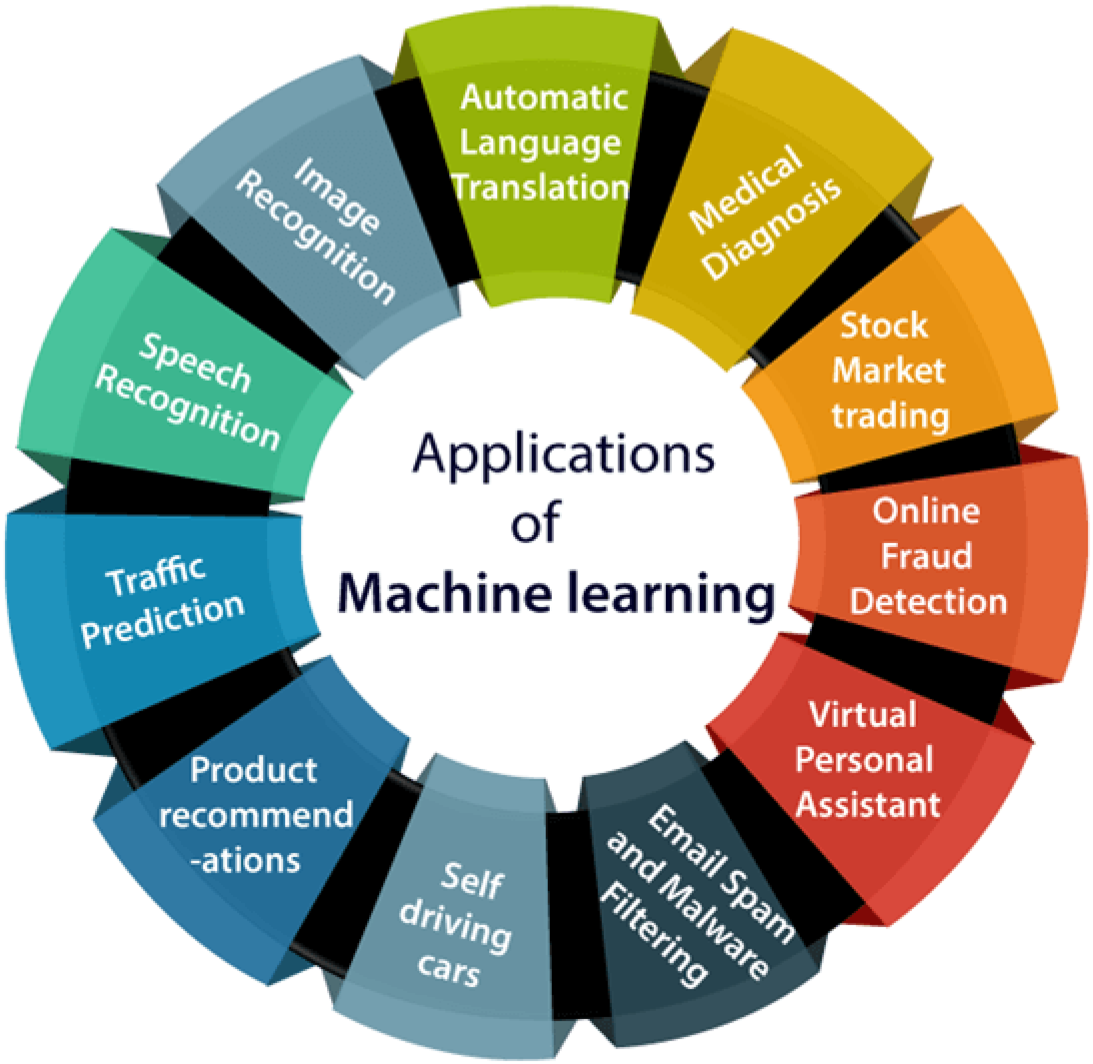
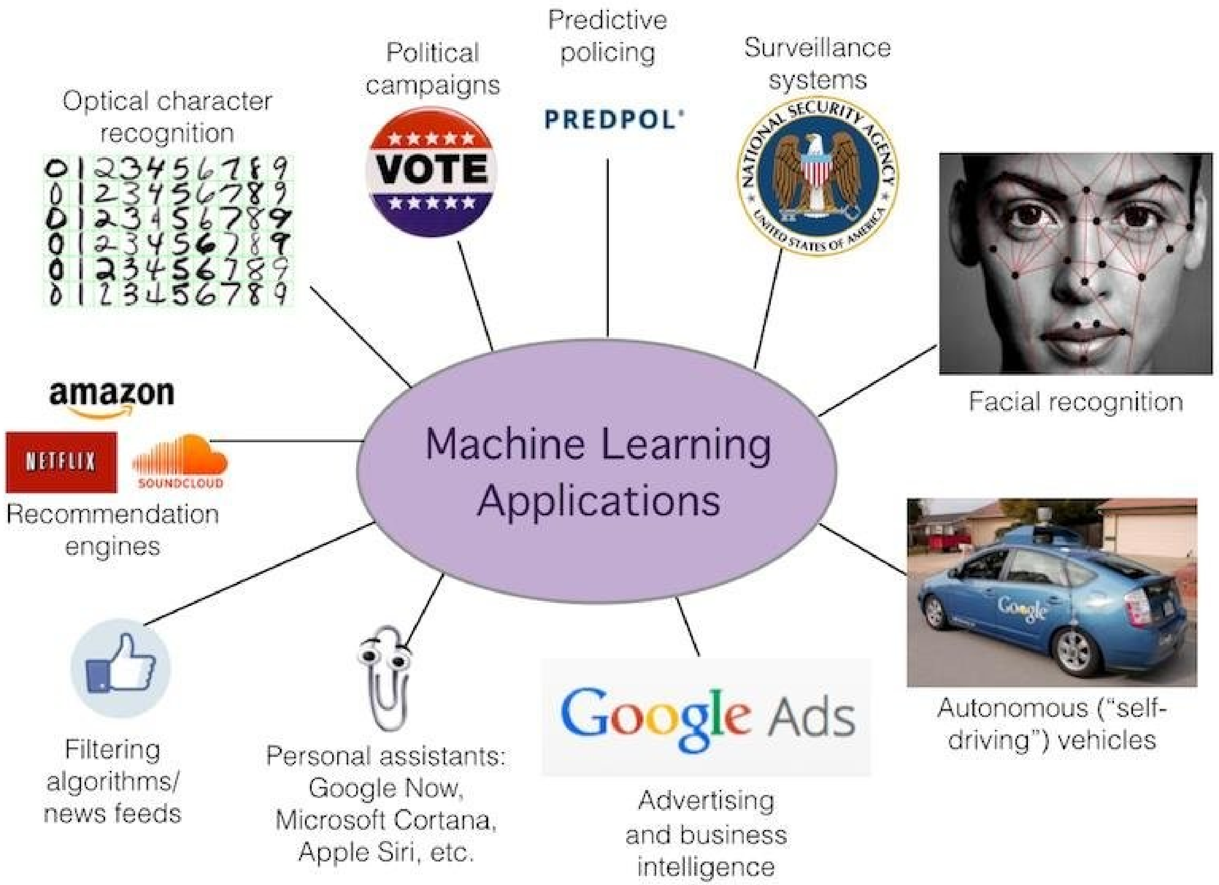
- How is the course conducted and assessed?

The Course …

- Why study MFML?
- How is the content organized?
- Where can I apply what I learn? **(REALLY?)**
- How is the course conducted and assessed?


Applications of Machine learning
Automatic Language Translation
Medical Diagnosis
Stock Market trading
Online Fraud Detection
Virtual Personal Assistant
Email Spam and Malware Filtering
Self driving cars
Product recommend -ations
Traffic Prediction
Speech Recognition
Image Recognition

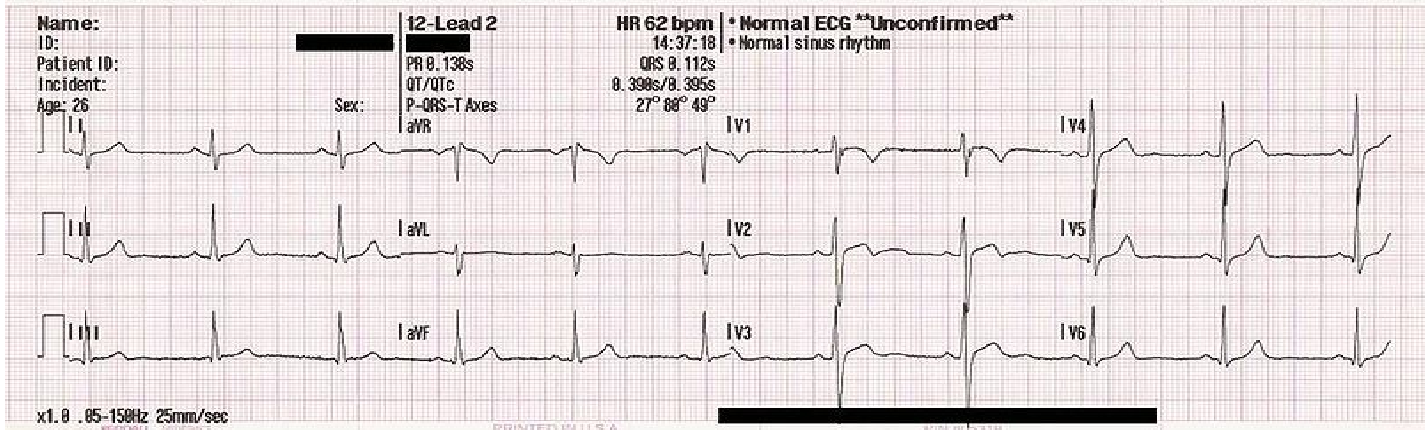

Machine Learning Applications
Optical character recognition
Political campaigns
VOTE
Predictive policing
PREDPOL
Surveillance systems
Facial recognition
amazon
NETFLIX
SOUNDCLOUD
Recommendation engines
Filtering algorithms/ news feeds
Personal assistants: Google Now, Microsoft Cortana, Apple Siri, etc.
Google Ads
Advertising and business intelligence
Autonomous ("self-driving") vehicles

Autonomous Systems

"Does your car have any idea why my car pulled it over?"

Bio-Medicine

Dr. Tinycat says your heart rate is normal
ICANHASCHEEZBURGER.COM


Name:
ID: [redacted]
Patient ID:
Incident:
Age: 26
Sex:

12-Lead 2
[redacted]
PR 0.138s
QT/QTc
P-QRS-T Axes

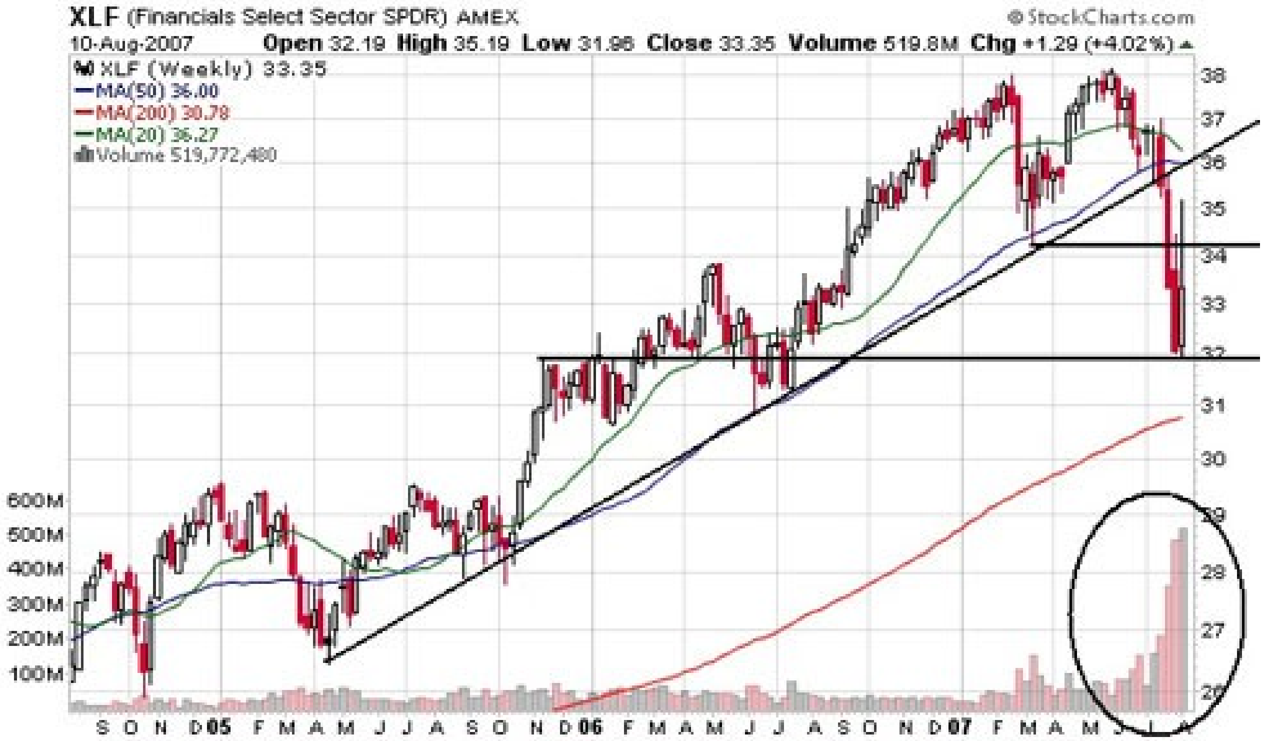
HR 62 bpm
14:37:18
QRS 0.112s
0.390s/0.395s
27° 88° 49°

• Normal ECG **Unconfirmed**
• Normal sinus rhythm

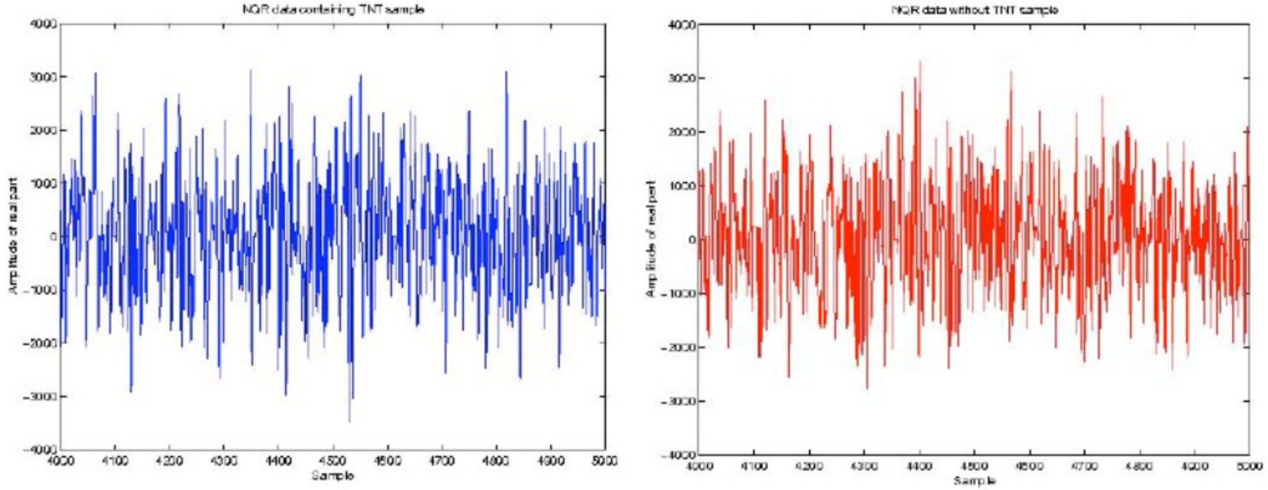
x1.0 .05-150Hz 25mm/sec
[redacted]

Finance

MATT DAVIES ©2010 Newsday
...WITH OUR NEW FINANCIAL REGULATIONS IT'S NOW SAFE TO INVEST YOUR MONEY...
MY WHAT?
HELP!


XLF (Financials Select Sector SPDR) AMEX
© StockCharts.com
10-Aug-2007 Open 32.19 High 35.19 Low 31.96 Close 33.35 Volume 519.8M Chg +1.29 (+4.02%)
XLF (Weekly) 33.35
MA(50) 36.00
MA(200) 30.78
MA(20) 36.27
Volume 519,772,480
38
37
36
35
34
33
32
31
30
29
28
27
26
600M
500M
400M
300M
200M
100M
S O N D 05 F M A M J J A S O N D 06 F M A M J J A S O N D 07 F M A M J J A

Chemistry


NQR data containing TNT sample
Amplitude of real part
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
Sample
NQR data without TNT sample
Amplitude of real part
Sample

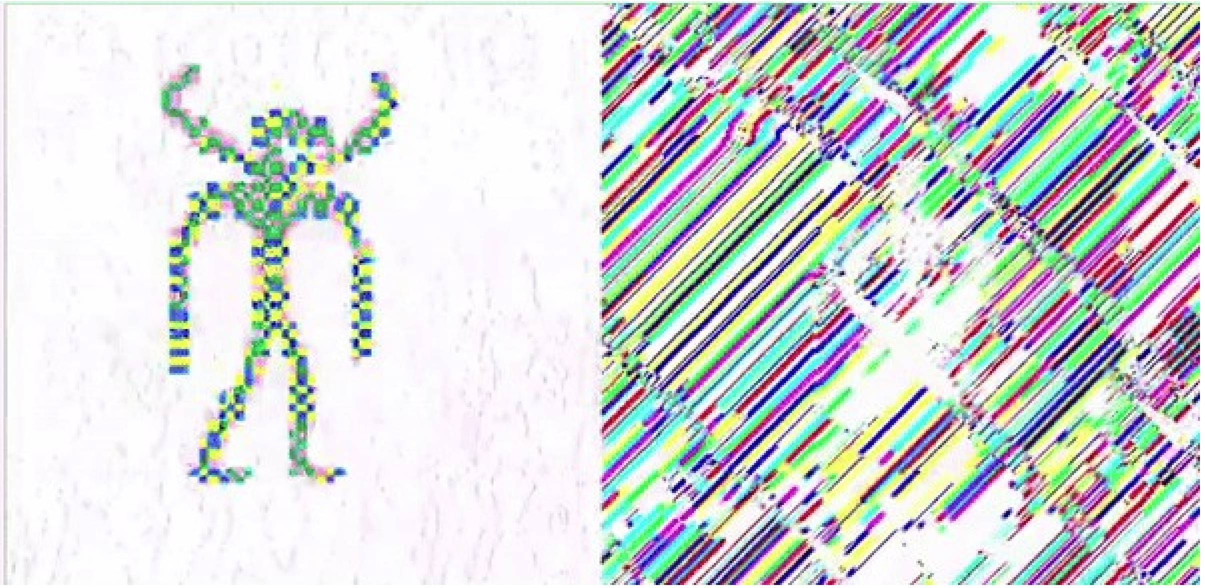
Finally understand what someone said 5000 years ago!

Finally understand what someone said 5000 years ago!

THE FUTURE — JULY 4, 2023

New AI translates 5,000-year-old cuneiform tablets instantly

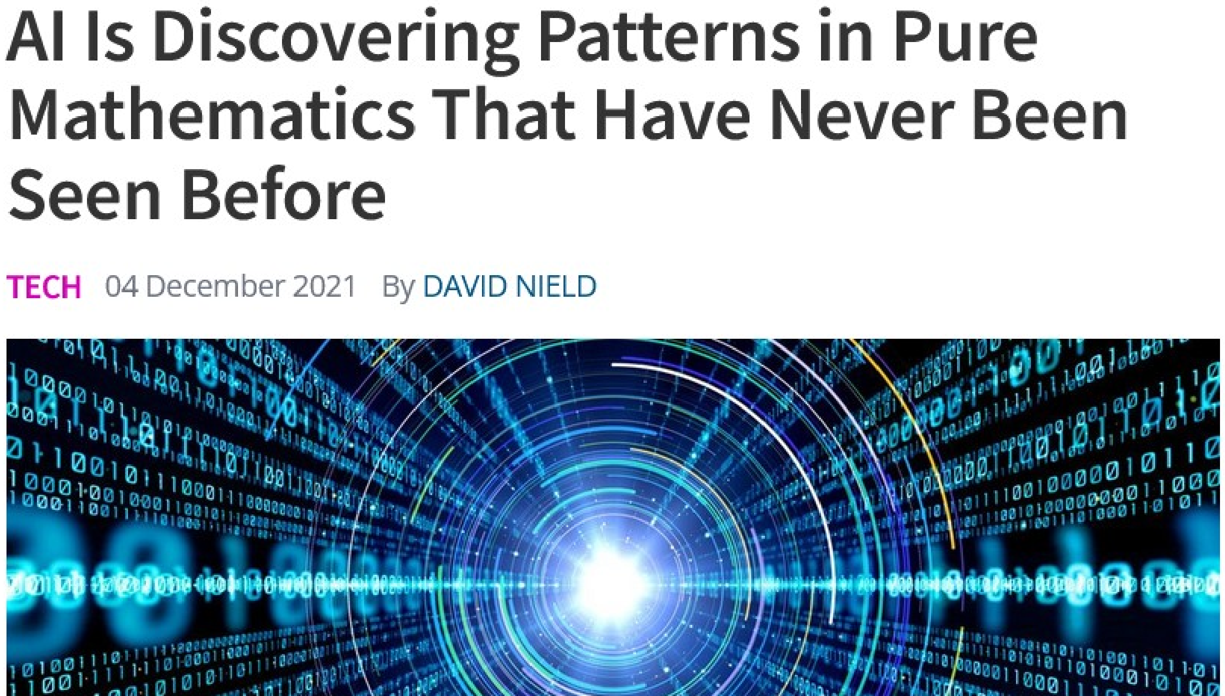
It's like combining Google Translate with a time machine.



A stamp-seal carved from grey steatite with a rhinoceros and an inscription in the Indus script, found at the Mohenjo-daro archaeological site in Sindh, Pakistan. The Trustees of the British Museum

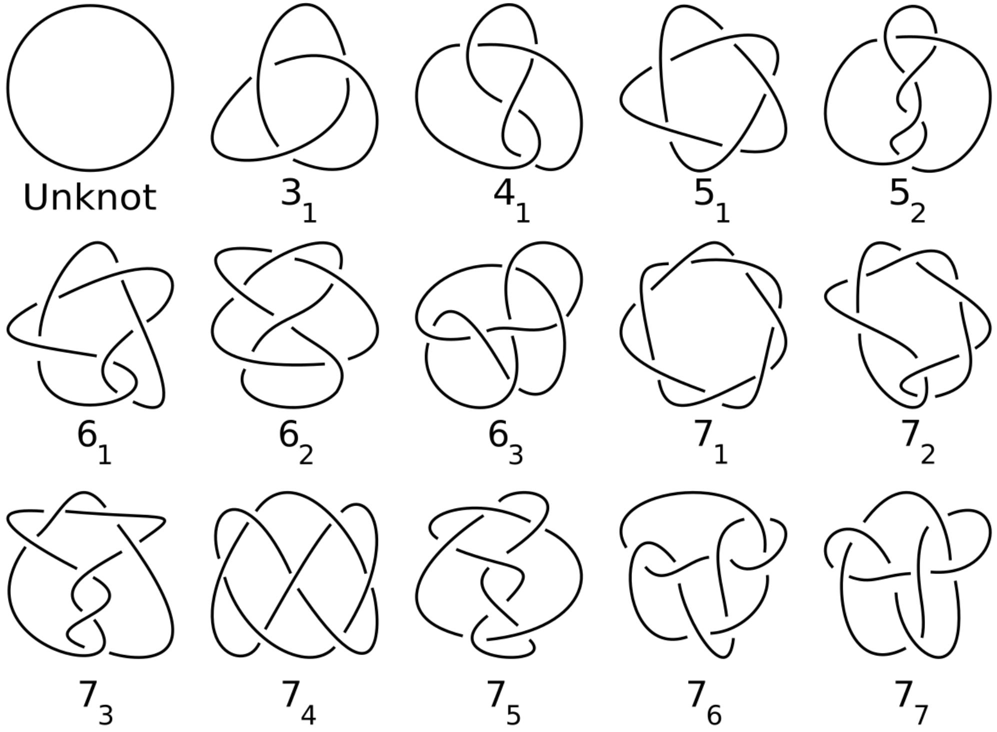
Or, just use it to prove new theorems…

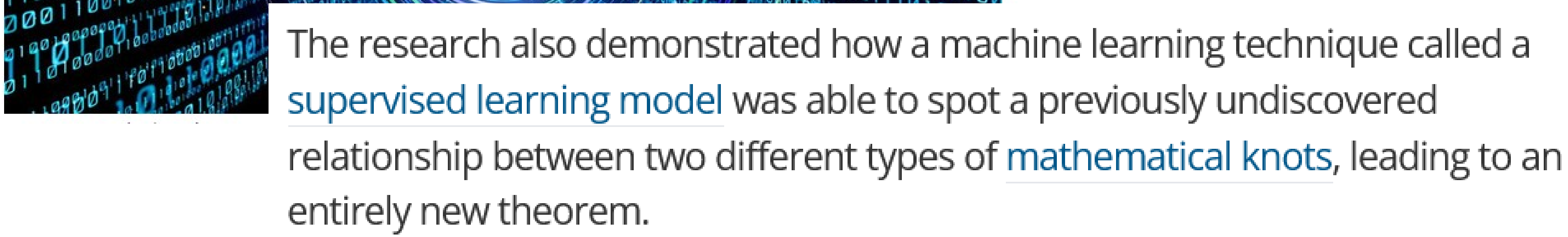
Or, just use it to prove new theorems…



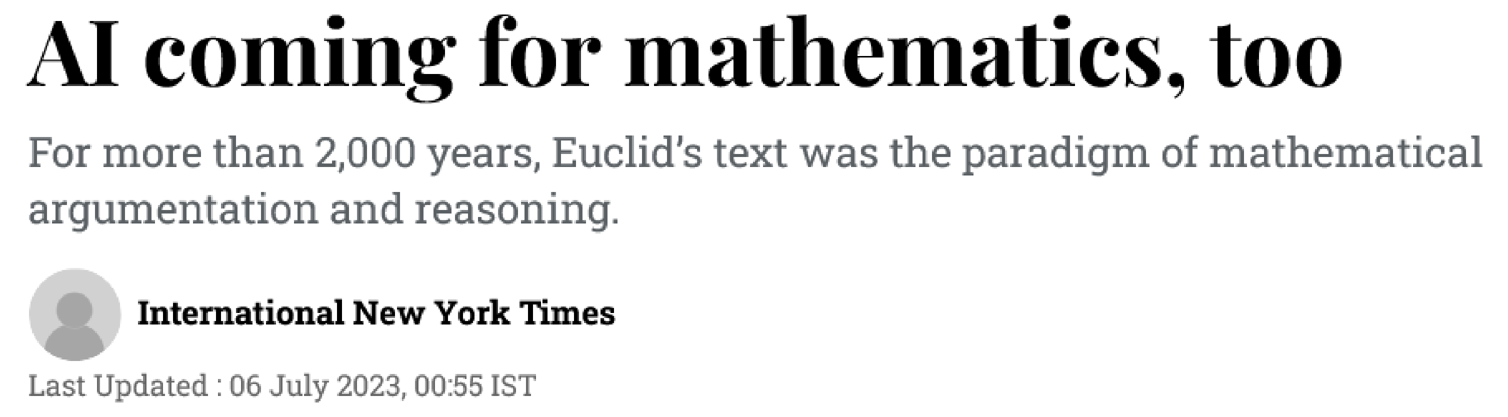
AI Is Discovering Patterns in Pure Mathematics That Have Never Been Seen Before

TECH 04 December 2021 By DAVID NIELD





The research also demonstrated how a machine learning technique called a supervised learning model was able to spot a previously undiscovered relationship between two different types of mathematical knots, leading to an entirely new theorem.

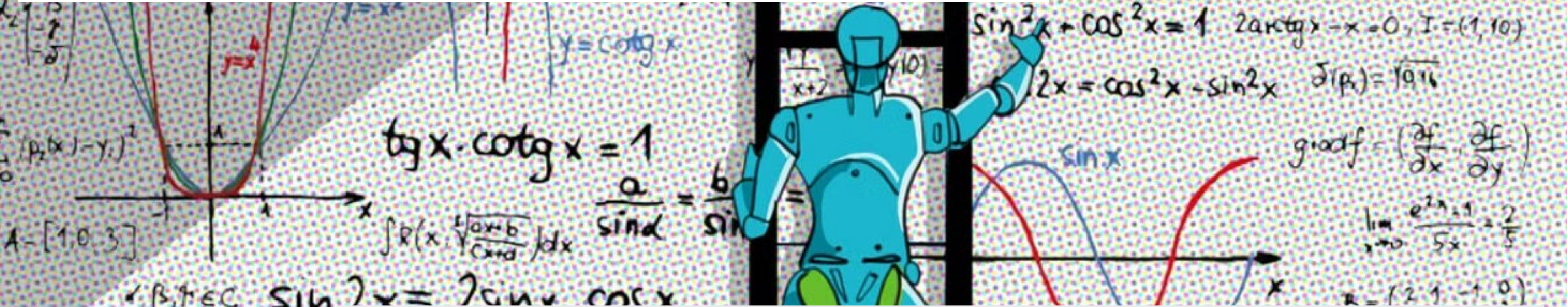


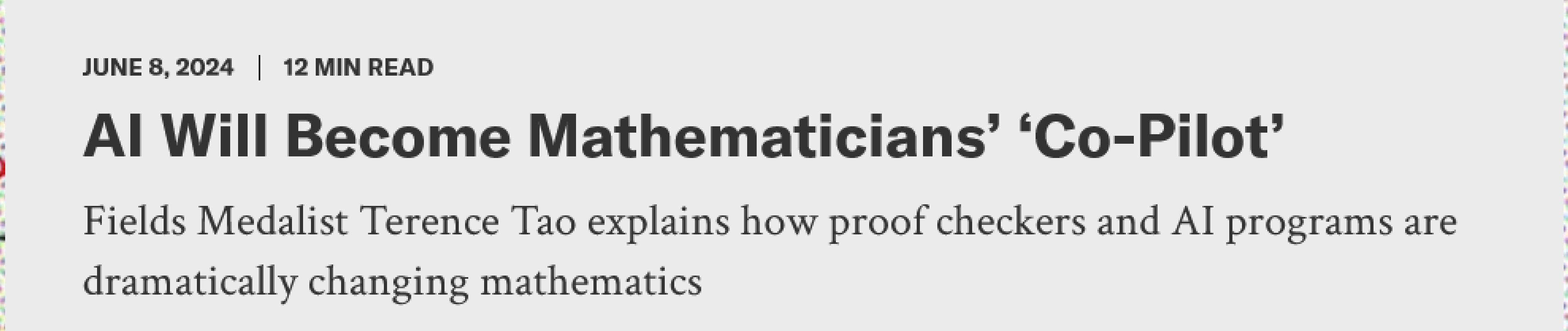
AI coming for mathematics, too

For more than 2,000 years, Euclid's text was the paradigm of mathematical argumentation and reasoning.

International New York Times

Last Updated : 06 July 2023, 00:55 IST



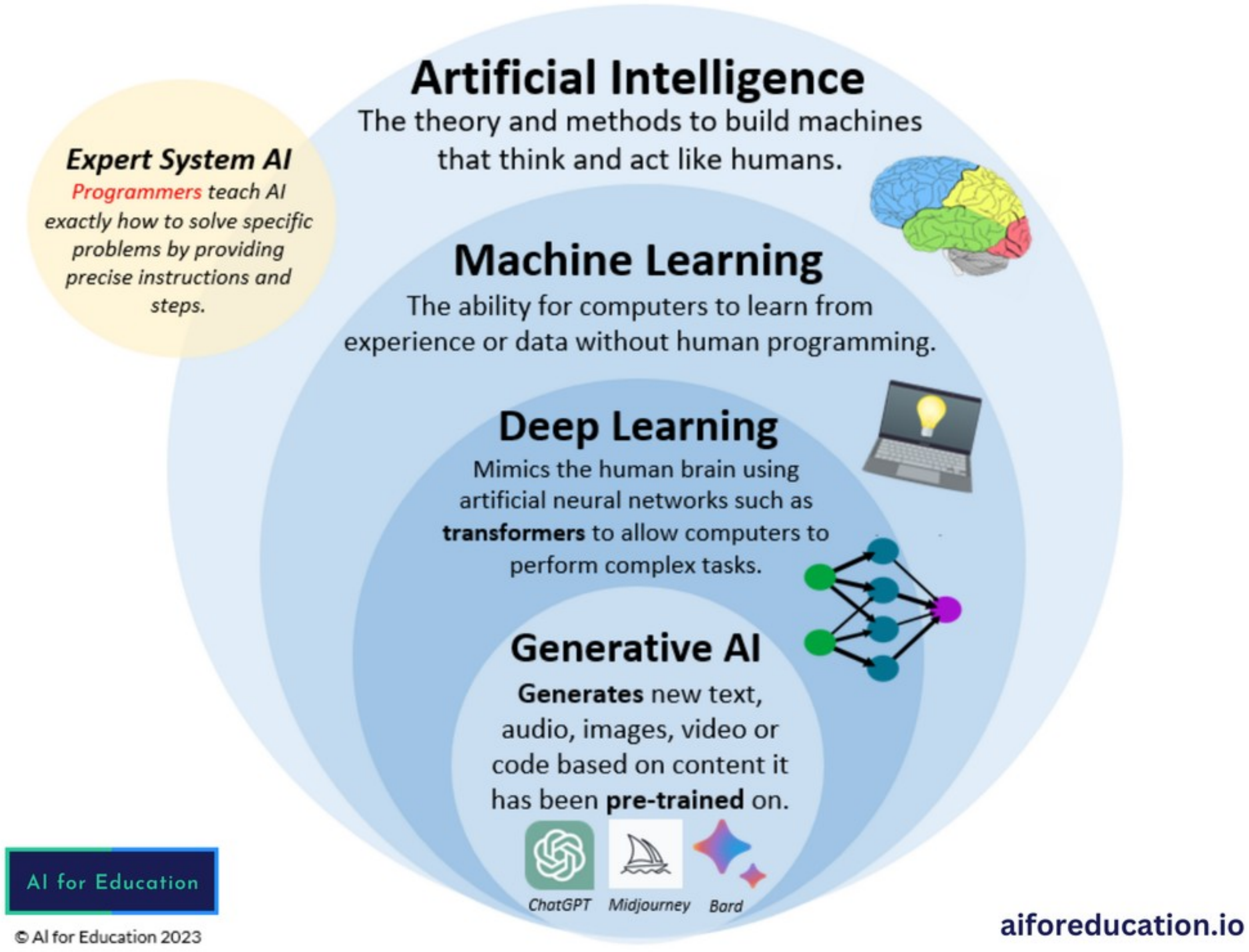


JUNE 8, 2024 | 12 MIN READ

AI Will Become Mathematicians' 'Co-Pilot'

Fields Medalist Terence Tao explains how proof checkers and AI programs are dramatically changing mathematics

Generative AI



Artificial Intelligence
The theory and methods to build machines that think and act like humans.

Expert System AI
Programmers teach AI exactly how to solve specific problems by providing precise instructions and steps.

Machine Learning
The ability for computers to learn from experience or data without human programming.

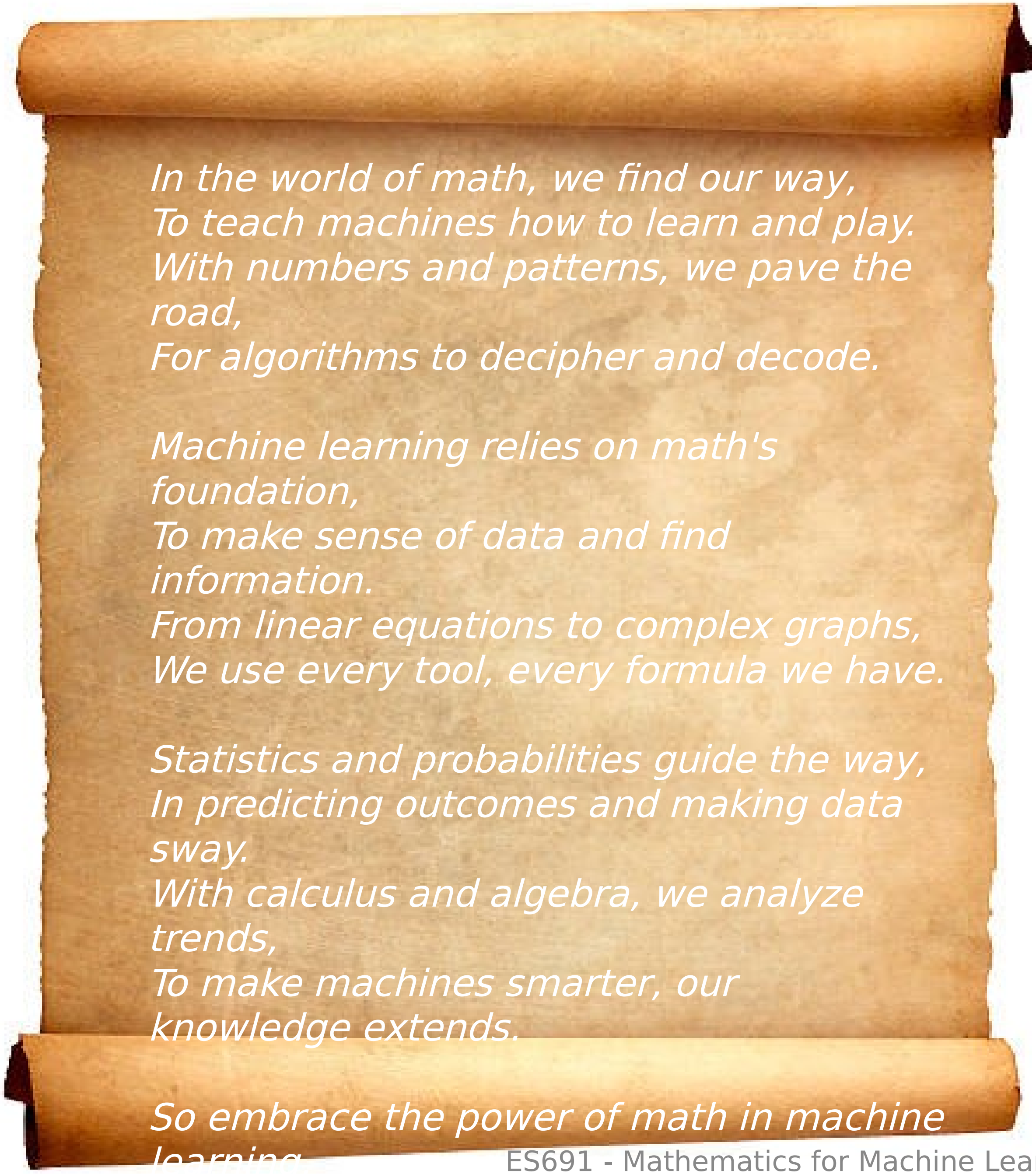
Deep Learning
Mimics the human brain using artificial neural networks such as **transformers** to allow computers to perform complex tasks.

Generative AI
Generates new text, audio, images, video or code based on content it has been **pre-trained** on.

© AI for Education 2023

aiforeducation.io

A Poem for Our Course



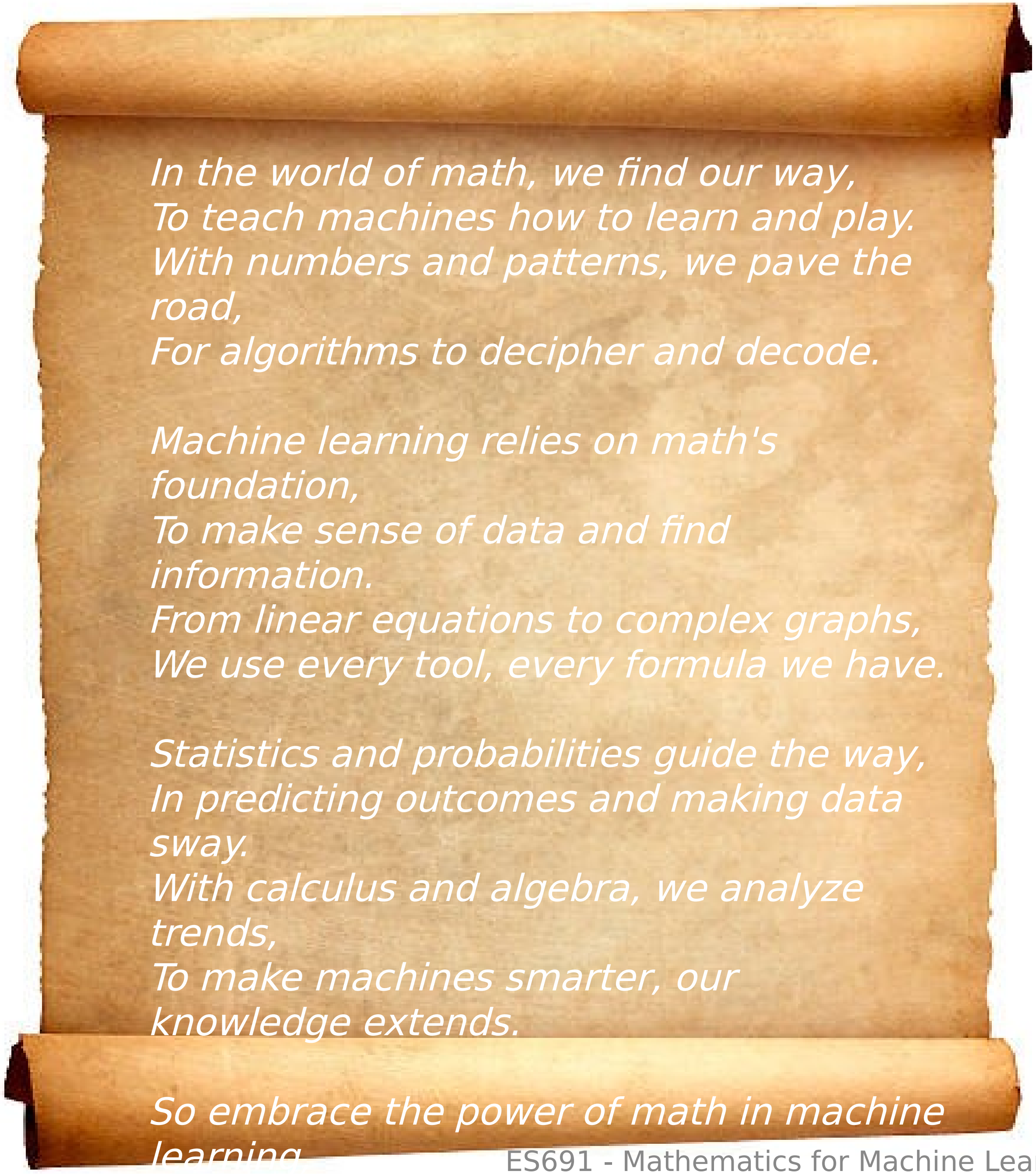
In the world of math, we find our way,
To teach machines how to learn and play.
With numbers and patterns, we pave the road,
For algorithms to decipher and decode.

Machine learning relies on math's foundation,
To make sense of data and find information.
From linear equations to complex graphs,
We use every tool, every formula we have.

Statistics and probabilities guide the way,
In predicting outcomes and making data sway.
With calculus and algebra, we analyze trends,
To make machines smarter, our knowledge extends.

So embrace the power of math in machine learning

A Poem for Our Course (AI Generated!!)



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The Course …

- Why study MFML?
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- How is the course conducted and assessed?

Important Business!!

- Policy, Outcomes, Textbooks, Marks Distribution etc.
  - **See provided course outline**
- Contact
  - naveed.butt@giki.edu.pk
  - office: FES G-6

Questions?? Thoughts??